

II.3 Solid State Energy Conversion Alliance Delphi SOFC

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Objectives

- Develop a 5-kW solid oxide fuel cell (SOFC) power system for a range of fuels and applications.
- Develop and demonstrate technology transfer efforts on a 3-10 kW stationary distributed power generation system that incorporates endothermic reforming of methane, and then natural gas.
- Initiate development of a 5-kW system for future mass-market automotive auxiliary power unit applications, incorporating endothermic reforming of gasoline.

Approach

- Develop and test major subsystems and individual components as building blocks for applications in targeted markets.
- Integrate major subsystems and individual components into a “close-coupled” architecture for integrated bench testing.
- Integrate major subsystems and individual components into a stationary power unit (SPU) for the stationary market.
- Integrate major subsystems and individual components into an auxiliary power unit (APU) for the transportation market.

Accomplishments

- Gen 3 cassettes (repeating units for stack) were successfully fabricated and tested. The Gen 3 cassettes have a 50% reduction in thickness and weight compared to Gen 2 cassettes. The cassettes are fabricated using high-volume manufacturing processes like stamping, brazing and laser welding.
- Over twenty Gen 2 stack subsystems were built and tested. Power density of 420 mW/cm^2 at 0.7 V/cell at 750°C was achieved in the stack laboratory with simulated recycle reformat. Thermal cycling tests in a furnace with 60 minutes heat-up from room temperature to 750°C demonstrated five thermal cycles with minimal degradation.
- Demonstrated 1617 W gross power in a Gen 2 APU. Solid model design geometry, computational fluid dynamics (CFD), finite element analysis (FEA), and thermal analysis were completed for the Gen 3 APU. Particular attention was placed on system pressure drop and thermal management concerns.
- Thirty-cell Gen 3 stacks were fabricated and tested (see Figure 1). Power density of greater than 500 mW/cm^2 at 0.7 V/cell at 750°C was achieved with simulated reformat.

- Extensive CFD analysis was completed on the integrated component manifold (ICM), process air module (PAM), and cathode air heat exchanger (CHEX) to reduce pressure drops within specified allocations and improve the temperature gradients in the SOFC plant.
- A new commercial combustible gas sensor has been sourced, and prototype samples have been ordered for possible implementation as part of system safety and diagnostics.
- The catalytic partial oxidation (CPOX) reformer has been further developed. Both gasoline and methane CPOX reformers are under test. We are currently developing the endothermic methane/natural gas and gasoline reformer technology. This technology will be utilized in the SPU demonstration system.
- A cart-based endothermic reformer/stack system was successfully tested for over 300 hours with reformat quality well within specified requirements.
- Designed a full-scale development system.
- Prepared initial detailed system cost estimate.



Figure 1. Gen 3 Solid Oxide Fuel Cell 30-Cell Stack

Future Directions

- Design, build and test a full-scale SPU demonstration system during Q2-Q4, 2005.
- Finalize detailed system cost estimate during Q3-Q4, 2005.
- Test the Delphi Demonstration System A SPU and operation of the system at the DOE National Energy Technology Laboratory site in Q4, 2005.

Introduction

The objective of this project is to develop a 5-kW solid oxide fuel cell power system for a range of fuels and applications. Delphi is developing a 3-10 kW system for stationary distributed power generation applications that incorporates endothermic reforming of natural gas. Delphi is also initiating development of a 5-kW system for later use in a mass-market automotive auxiliary power unit. The automotive unit will incorporate endothermic reforming of gasoline.

These two complementary fuel cell systems will be introduced to their respective markets: the distributed power generation market for electric power and the transportation systems market for advanced automotive power trains. Developing both industrial and transportation applications based on similar components increases the potential production volumes of the components and therefore reduces the potential cost.

Approach

Delphi's approach is to evaluate components and subsystems at increasingly integrated levels. The system integration levels are Level 0, Level I, and Level II. Level 0 integration represents the individual testing and development of the major subsystems and components. Level I integration represents the close coupling of the major system modules such that all major system functions are represented and functional during the test. Level II integration represents the final product package, integration, and function for the SOFC power plant, or APU as shown in Figure 2. In the laboratory, a stand is employed to hold the product and facilitate fuel, air, electrical, and exhaust connections, but the intended construction and function of the system should be representative of product intent at this integration level.



Figure 2. SOFC APU System Modules

Results

The Generation 3 (Gen 3) auxiliary power unit (APU) was adapted for use as a stationary power unit (SPU 1) by replacing the Gen 3.0T gasoline catalytic partial oxidation (CPOX) fuel reformer with the new Gen 4.1T CPOX (see Figure 3) natural gas fuel reformer. This design was the target for first system integration and test of a methane-fueled SPU.

The electrical and electronics system has advanced in several areas. A variety of studies have resulted in electrical architecture designs for development and potential future product applications. Innovation in the power and signal distribution subsystem enables simplified system integration, commonality across applications, and reduced debug efforts. The electrical and electronics system has advanced towards a more production intent implementation.

Cathode development efforts have been focused on improving the long-term durability of (La,Sr)(Co,Fe)O₃ (LSCF) cathodes for use in Cr-free operation. Interconnect development focused on improving cathode and anode contact as well as minimizing Cr interaction with the cathode. Stack results have demonstrated power densities of greater than 500 mW/cm² at 0.7 V at 750°C operating temperature. Stacks have demonstrated greater than 2000 hours continuous durability with less than 10% degradation (less than 1% in the last 1000 hours). Thermal cycling tests have shown greater than 5 thermal cycles with no degradation in power.

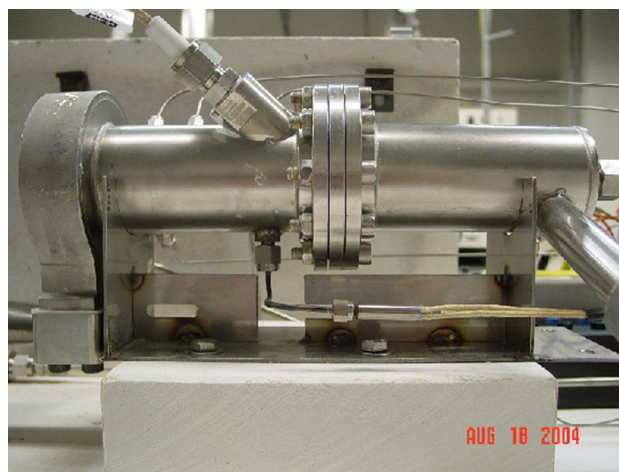


Figure 3. Tubular CPOX Reformer Assembly

Process air module (PAM) components have been built and tested on dynamometer and airflow stands. Since the PAM is a major contributor to parasitic power loss, particular attention is being given to identifying the sources of the PAM losses. Test data is used to refine the CFD analysis model so that alternative manifold design features can be studied to reduce the PAM power losses. Thermal testing of an instrumented motor and controller was completed at worst case ambient temperature conditions so that the minimum airflow limit of the air-cooled PAM could be established. Durability testing of the motor and controller is ongoing.

Prototype part fabrication of a third-generation integrated component manifold was completed. This design incorporated a new gas phase combustor (GPC). Results from system tests indicated improved gas distribution, improved gas mixing, and reduced pressure drop in the manifold. Improved GPC light-off and sustained ignition was also achieved with this GPC design.

Reformer catalyst durability was demonstrated to over 2000 hours for steady-state partial oxidation of gasoline fuel while meeting acceptable reformat quality. Modifications were made to the durability test to permit similar studies with natural gas or diesel fuels. The durability test was modified to match differing APU power requirements by cycling through five different sets of operating conditions. Catalyst formulations were identified for partial oxidation of low-sulfur diesel fuel, and appropriate processing regimes and catalysts were identified for

processing of diesel fuel containing up to 50 ppmw sulfur.

Conclusions

- Reformer changes (from gasoline to natural gas) permit the stack and balance of plant to be applied as an auxiliary power unit (mobile) or as a stationary power unit.
- Hardware durability increases are achieved by managing Cr in the balance of plant and by refining catalysts in the reformer.
- Continued development of balance of plant and reformer, in addition to basic stack work, is essential to delivering a product that can operate on real-world liquid and gaseous fuels, including those with minimal typical sulfur content.

Special Recognitions & Awards/Patents Issued

1. Patent issued: The U.S. Patent Office Grant Numbers: 6759155, 6773845, 6786254, 6821667, 6830844, 6893768

FY 2005 Publications/Presentations

1. November 2004: 2004 Fuel Cell Seminar, San Antonio, TX: Presentation only
SOFC APU Development Update
Steven Shaffer
Delphi Corporation
2. January 2005: SECA Core Technology Workshop, Tampa, FL: Presentation only
Material Interconnect Development
Dr. Diane England
Delphi Corporation
3. April 2005: SECA Annual Workshop, Pacific Grove, CA: Presentation only
Development Update on Delphi's Solid Oxide Fuel Cell System
Steven Shaffer
Delphi Corporation
4. May 2005: SOFC IX - Industrial Workshop, Quebec, Canada: Presentation only
Development Update on Delphi's Solid Oxide Fuel Cell System
Steven Shaffer
Delphi Corporation
5. May 2005: SOFC IX - Industrial Workshop, Quebec, Canada: Presentation only
Development Update on Delphi's Solid Oxide Fuel Cell Stack
Subhasish Mukerjee
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